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# A 5-FREQUENCY RADIOMETER ANTENNA SYSTEM FEED HORN



Final Report
Contract NAS5-20637
June 1976

Prepared for

NASA, GSFC
Greenbelt, Maryland



COMSAT Laboratories
Clarksburg, Maryland 20734

A FIVE-FREQUENCY RADIOMETER

ANTENNA SYSTEM FEED HORN

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## I. INTRODUCTION

This report is being submitted to NASA, Goddard Space Flight Center, Greenbelt, Maryland, by COMSAT Laboratories, Clarksburg, Maryland under Contract NAS5-20637 (Modification 2). This report describes the final design of a five frequency radiometer feed.

The purpose of this contract was to design and demonstrate the feasibility of multiplexing five narrow band frequencies 6.6, 10.7, 18.5, 21.5 and 33 GHz onto a single receive feed employing dual linear polarization at each frequency with a better than 25 dB isolation between each polarization.

This work was first reported on under Contract NAS5-21986 in a Final Report dated December 1974.[1] This report described the development of a breadboard model of the five frequency horn and the preliminary results which were achieved. Additional engineering development was recommended to determine the acceptability of this horn for five frequency operation as an onboard radiometer system with a Nimbus satellite. Tasks recommended were related to the finline coupler, the dielectric rod launcher and the 10.7 GHz launching section.

In this report the final overall design is described and results are presented showing that this design concept has an acceptable electrical performance.

## II. MULTIFREQUENCY FEED SPECIFICATIONS

The purpose of this contract was to establish the feasibility of operating a five frequency feed as a radiometer for use on board a Nimbus type satellite. Specifically the contract work concentrated on the production of a horn design which can illuminate a parabolic reflector segment with an f/D ratio of approximately 0.4, producing an edge illumination of approximately -20 dB. The specifications for the feed are as follows:

(i) Frequencies: 6.6, 10.7, 18.5, 21.5 and 33.0 GHz,

(ii) VSWR: $\leq$ 1.2:1,

(iii) RF Losses: < 0.4 dB, and

(iv) Polarization Isolation: $\approx$ 25 dB

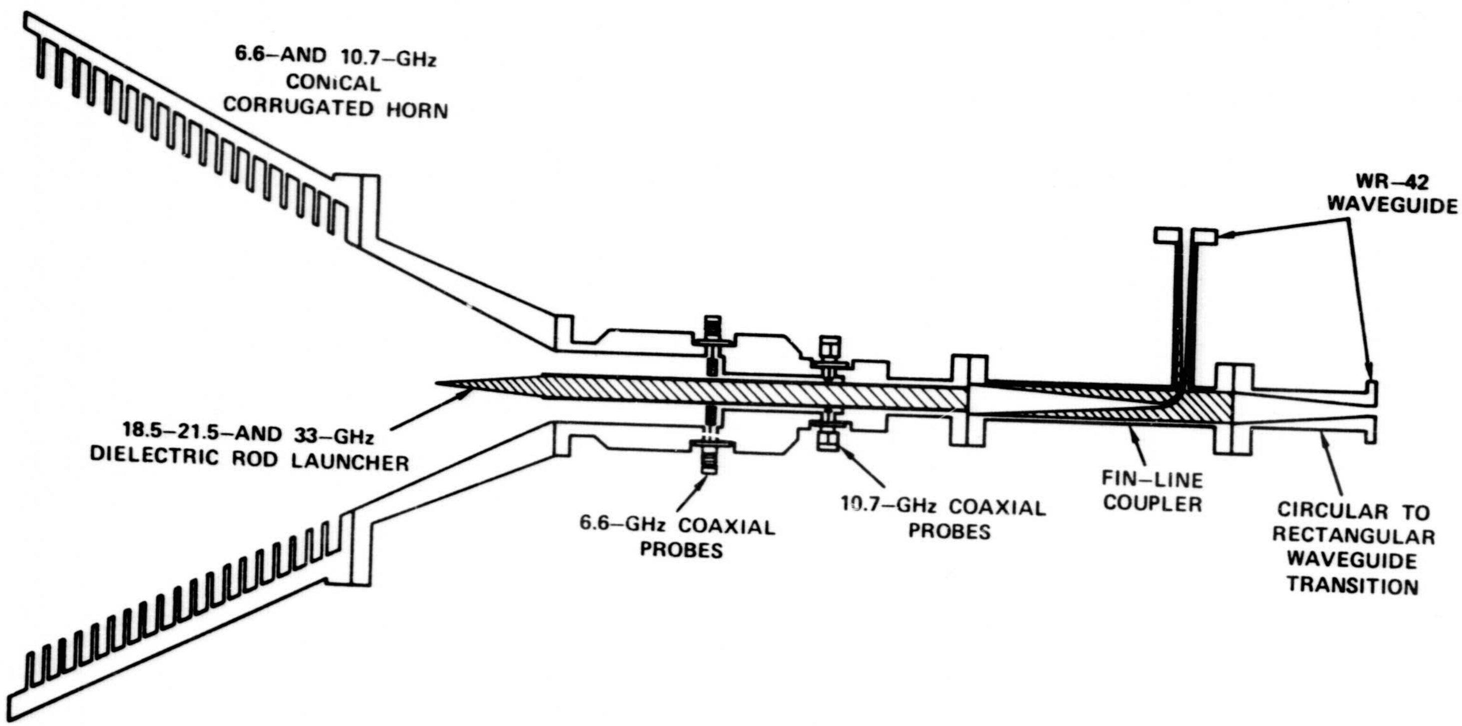
It should be emphasized that these specifications were to be treated as design goals since the primary task was to establish the feasibility of the design concepts.

## III. DESCRIPTION OF FIVE FREQUENCY FEED

The final design of the five frequency feed is shown in Figures 1 thru 3. The basic design philosophy was to separate the five frequencies by using a coaxial section with a hollow center conductor. The coaxial section was used to launch the two lower frequencies while the hollow center conductor was used as a circular waveguide to launch the three higher frequencies. The $TE_{11}$ mode was used for all five frequencies so that a satisfactory match to a free space plane wave could be achieved using a corrugated horn transducer. The $TE_{11}$ mode also enables spacially orthogonal fields at each frequency to be generated with excellent polarization isolation (> 30 dB) performance. This was achieved at 6.6 and 10.7 GHz with the coaxial $TE_{11}$ mode by using orthogonal probes while at the higher frequencies a finline coupler was used for orthogonal field separation. Figure 3 is a photograph of the feed ports of the five frequency feed system. The coaxial ports are shown along with one orthogonal port of the waveguide section.

The three pertinent features of the feed design are therefore the coaxial section, the waveguide section (including the finline coupler) and the corrugated horn (including the dielectric tapered launcher). Detailed description of the designs of each of these parts will be given in the following sections.

FIGURE 1. 5 FREQUENCY WIDEBAND FEED (DUAL LINEAR POLARIZATION
CROSS-SECTIONAL VIEW



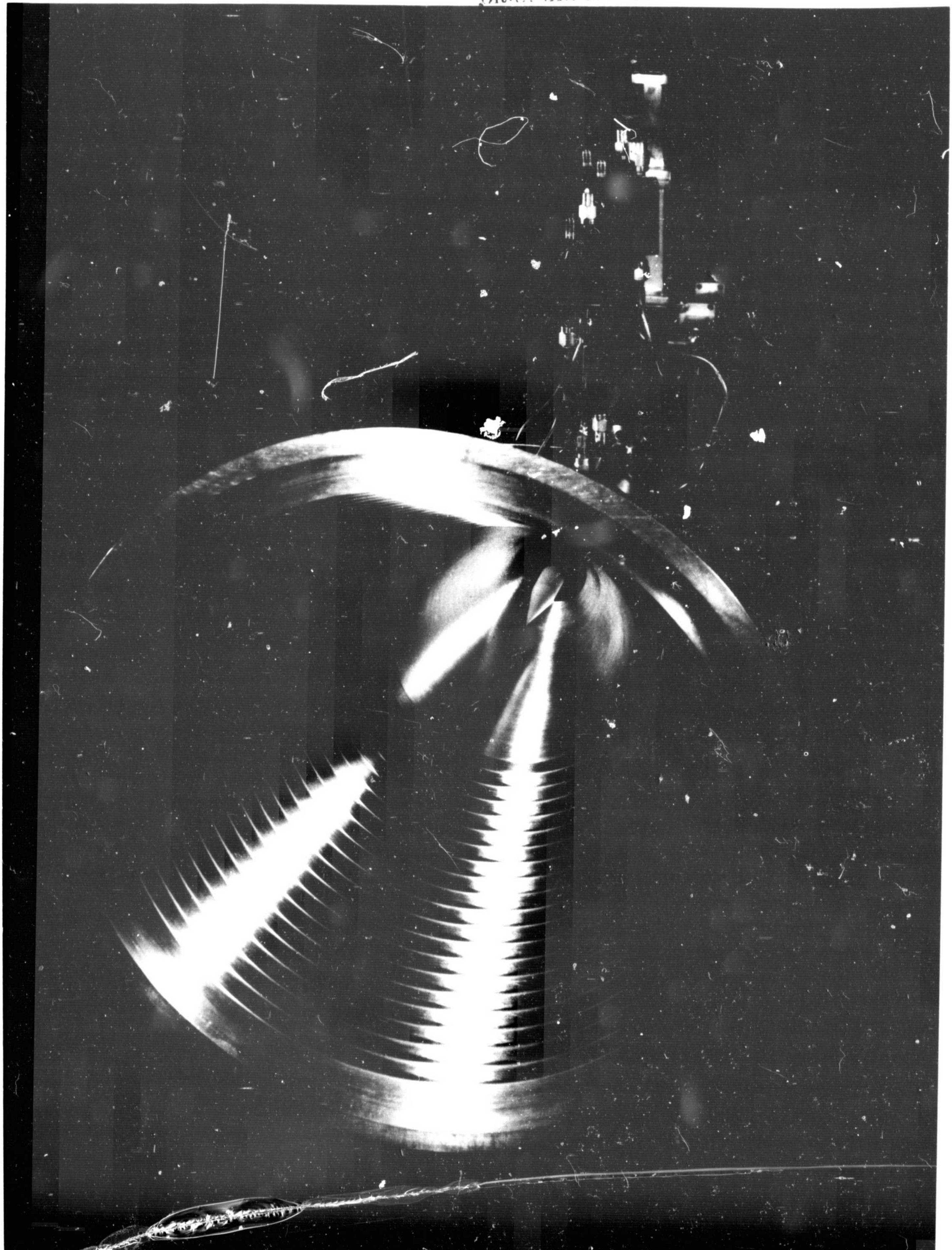


FIGURE 2. 5 FREQUENCY FEED HORN

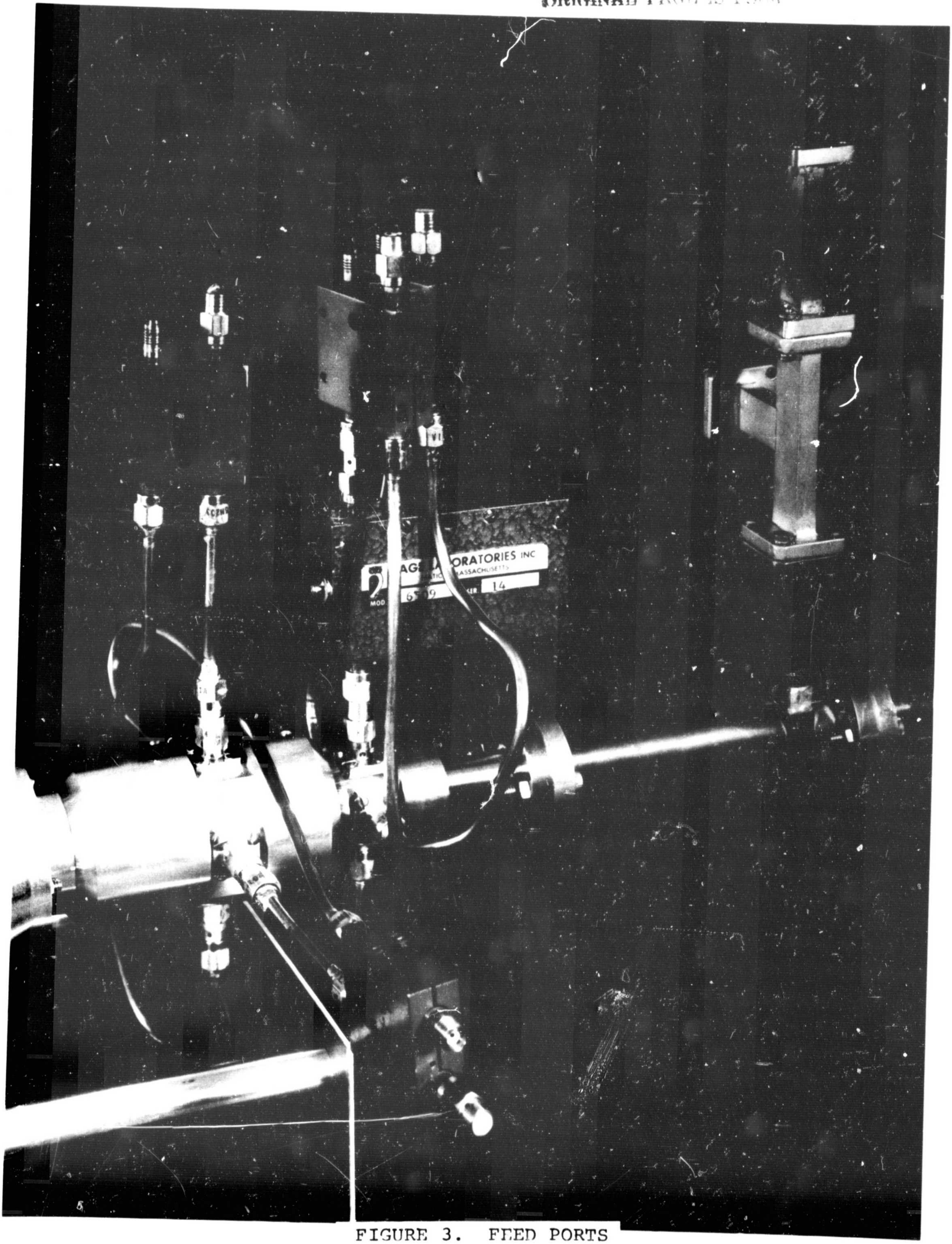



FIGURE 3. FEED PORTS

## IV. ANALYSIS AND DESIGN OF COAXIAL SECTION

A detailed study was carried out on the original coaxial launching section to determine why the 10.7 GHz radiation pattern was not satisfactory.[1] It was finally determined that unavoidable interaction between the 6.6 GHz and 10.7 GHz launching probes was present and that the coaxial section would have to be redesigned. Figure 1 illustrates the design which was finally achieved.

The coaxial launching section operates in the higher order $TE_{11}$ mode and the two frequencies are spacially separated by using two different outside diameter coaxial sections with a common inside diameter. Generation of the coaxial $TE_{11}$ mode was accomplished by using two symmetrical opposite probes fed with equal amplitudes but with a phase difference of 180°. This is illustrated in Figure 4.

The dimensions of the coaxial sections were chosen so that the higher order ($> TE_{11}$ mode) coaxial modes do not propagate at the feed frequencies. A common inside diameter of 0.36" was chosen* with the larger section having an outer diameter of 1.00" and the smaller section having an outside diameter of 0.466". Table I illustrates the cutoff frequencies of the lower order modes in the two coaxial sections.

The coaxial step represents a short circuit for the 6.6 GHz and its position was adjusted to provide a good return loss at 6.6 GHz. The step prevents any coupling of the 6.6 GHz frequency into the 10.7 GHz probes. The position of the short circuit at the back of the smaller coaxial section was adjusted to enable a good match at 10.7 GHz to be obtained. To prevent coupling of the 10.7 GHz into the 6.6 GHz a 5 section low pass filter ($f_c \approx 7$ GHz) was

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*This dimension had to be compatible with the propagation of the three higher frequencies in circular waveguide.

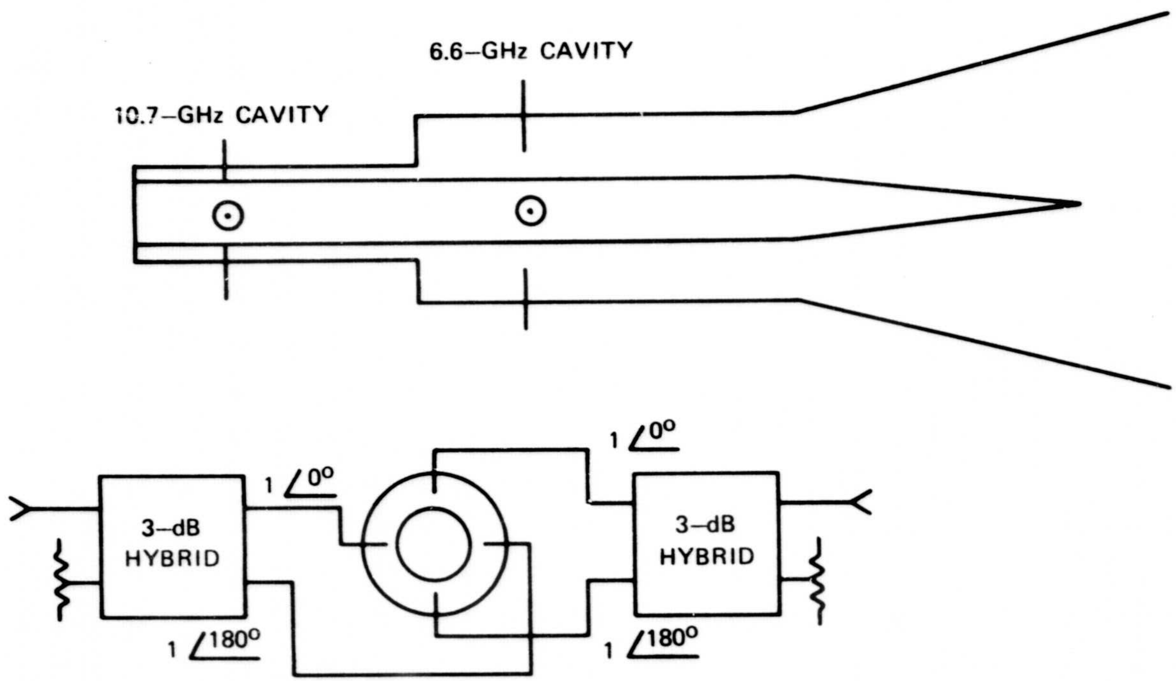


FIGURE 4. 6.6 AND 10.7 GHz LAUNCHING SECTION

built into the 6.6 GHz probes. At both frequencies mode purity was tested by rotating a lightly coupled probe around the coaxial section's outer diameter and in all cases the TEM mode was found to be at least 30 dB below the required $TE_{11}$ mode.

TABLE I

| Coax O.D. = 1" I.D. = 0.36 | | Coax O.D. = 0.466" I.D. = 0.36 | |
|---|---|---|---|
| mode | cutoff frequency | mode | cutoff frequency |
| TEM | 0.0 GHz | TEM | 0.0 GHz |
| $TE_{11}$ | 5.5 GHz | $TE_{11}$ | 9.1 GHz |
| $TE_{21}$ | 10.63 GHz | $TE_{21}$ | 16.3 GHz |
| $TE_{31}$ | 15.53 GHz | $TE_{31}$ | 25.3 GHz |

## V. DESIGN OF THE FINLINE COUPLER

To achieve separation of the two orthogonal linear polarizations at 18.5, 21.5 and 33 GHz a wideband finline coupler was employed.[2]

A dual linear polarized signal enters the coupler in 0.44" diameter circular waveguide (see Figure 5). The signal with the electric field parallel to the fin is guided out the shunt port while the fin is transparent to the orthogonal polarization.

The back port has a maximum insertion loss of 0.4 dB at 18.5 GHz as seen in Figure 6. The insertion loss is 0.1 dB at 21.5 GHz and 0.3 dB at 33 GHz as seen in Figures 6 and 8. It is important to note that the finline coupler creates higher order asymmetric modes above 26 GHz due to the 0.44 inch diameter guide and therefore the fin dimensions must be judiciously chosen to prevent these modes occurring at 33 GHz.

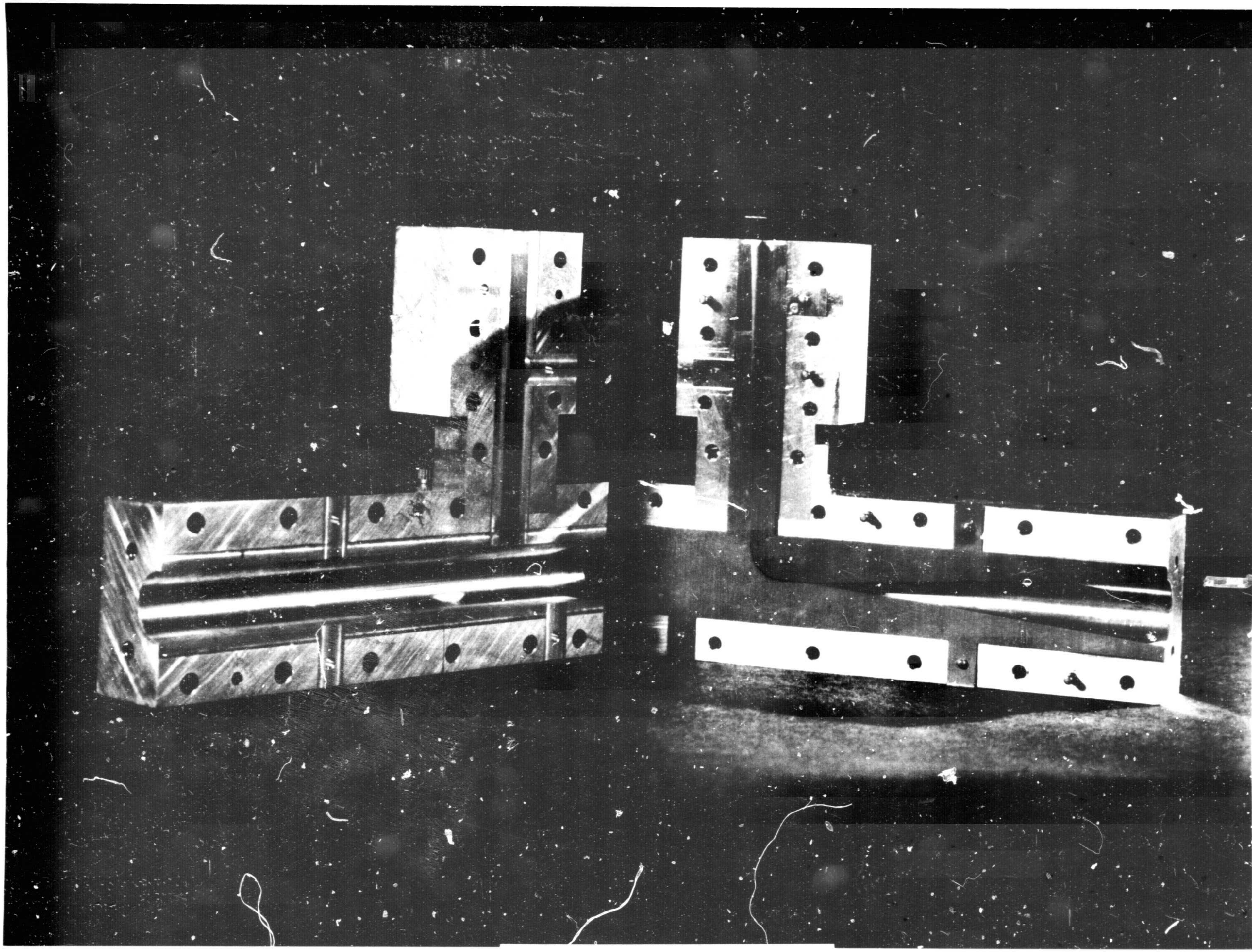

FIGURE 5. FINLINE COUPLER

The shunt port employs tapered ridged waveguide technology for impedance matching. The small gap in the fin which guides the shunt port energy must be critically chosen for the desired frequencies. Too large a gap creates higher order modes while too small a gap causes excessive dissipative losses as can be seen in Figures 7 and 9.

## VI. DESIGN OF THE DIELECTRIC ROD LAUNCHER AND CORRUGATED HORN

Since the successful design of the coaxial launching section necessitated a center conductor outside diameter of only 0.36", the maximum inside diameter of the circular waveguide launcher was restricted to 0.30". Therefore, to achieve an equivalent free space diameter of 0.44" the circular waveguide is loaded with teflon ($e_r$ = 2.08).

The teflon center conductor is tapered in order to achieve a satisfactory impedance match into free space (see Figure 10). This taper also increases the on-axis gain by 5 dB with respect to an open ended circular waveguide at 18.5 and 21.5 GHz as shown in Figures 15 and 16.

The corrugated horn for the two lower frequencies (6.6 and 10.7 GHz) consists of two assemblies (Figures 1 and 2 in the appendix). The corrugations are designed such that a capacitive reactance is seen at the desired frequencies of operation. Past experience has established that the minimum corrugation density (corrugations per wavelength at the highest frequency) is three sections per wavelength, where a section is defined as one tooth and one space. It has also been established that better electrical performance is obtained by minimizing the thickness of the teeth. Accordingly, the corrugation dimensions chosen are shown in Figure 1 of the appendix.[3]

INSERTION LOSS - BACK PORT

FINLINE COUPLER #2

8/6/75 F.F.

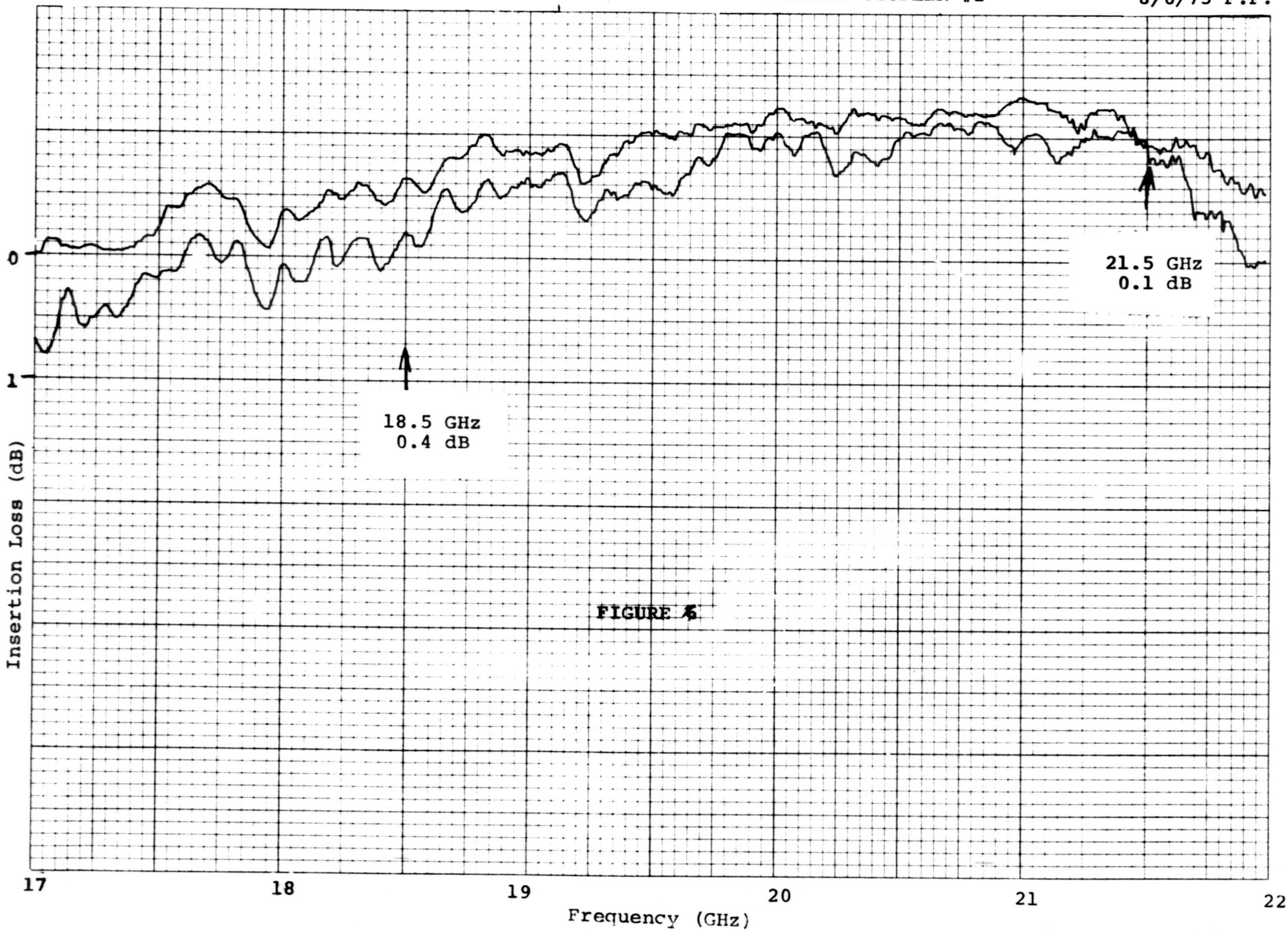


FIGURE 6

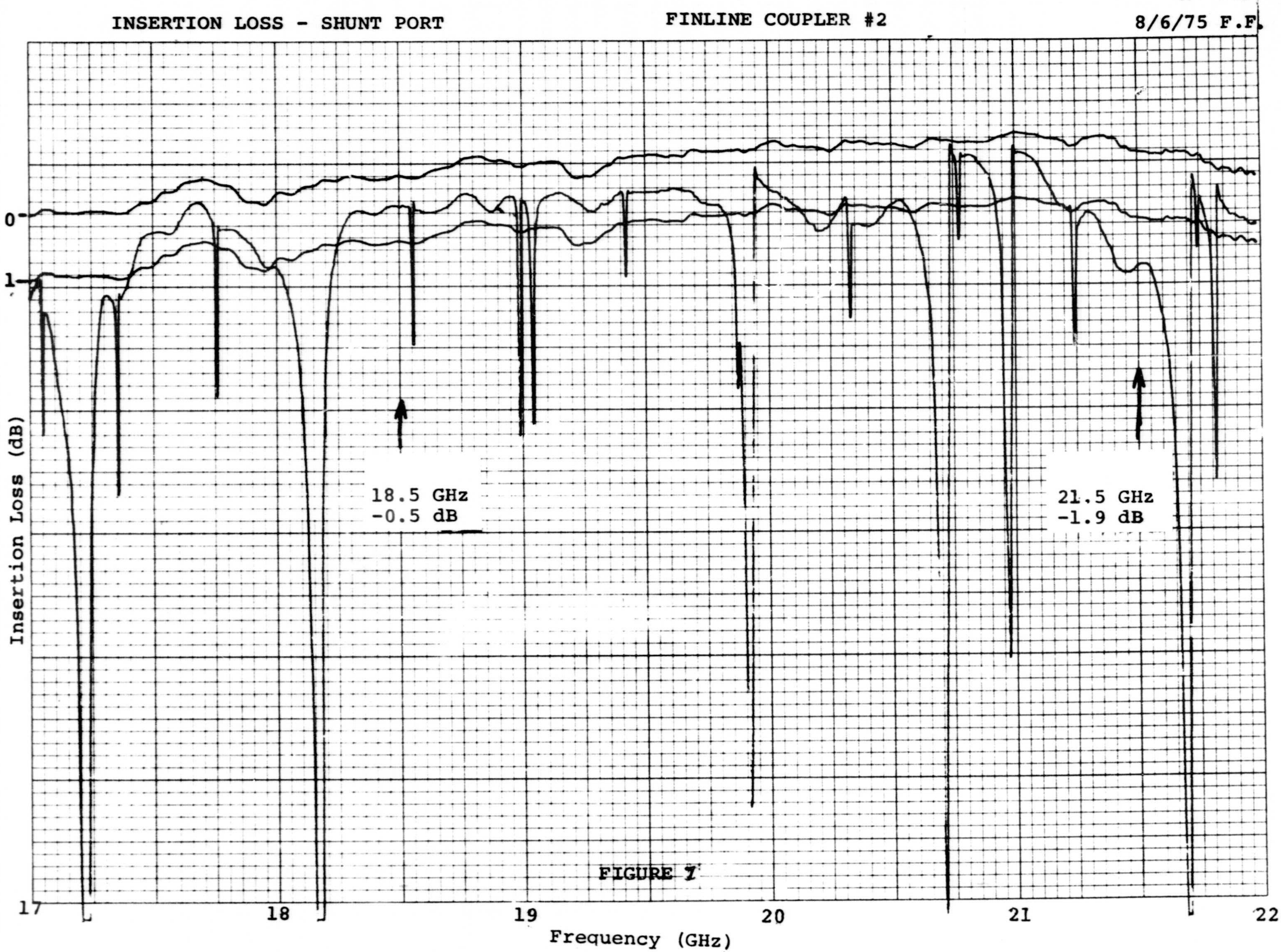
INSERTION LOSS - SHUNT PORT
FINLINE COUPLER #2
8/6/75 F.F.
0
1
Insertion Loss (dB)
18.5 GHz
-0.5 dB
21.5 GHz
-1.9 dB
17
18
19
20
21
22
Frequency (GHz)

FIGURE 7

INSERTION LOSS - BACK PORT

FINLINE COUPLER #2

8/6/75 F.F.

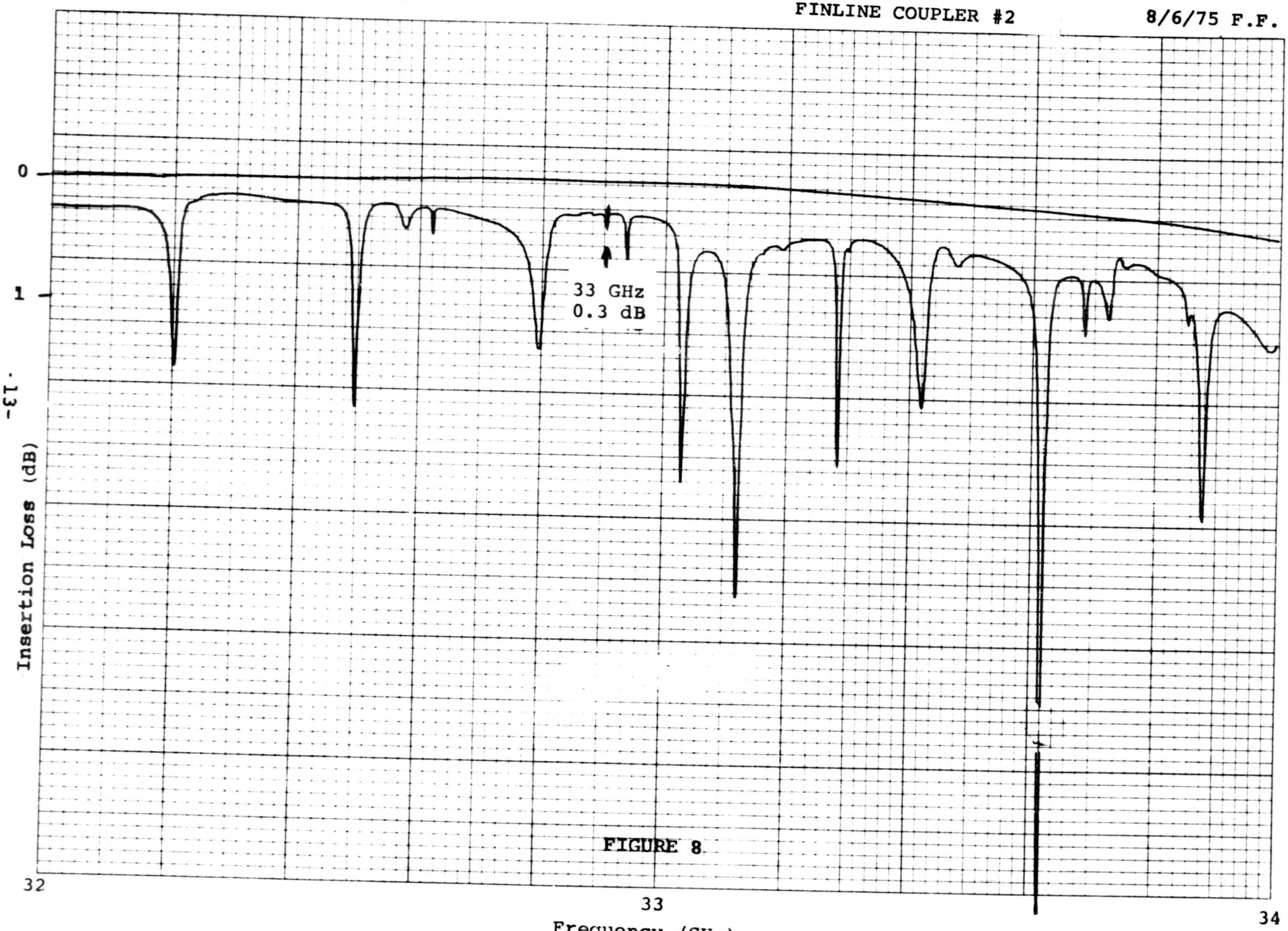


FIGURE 8

INSERTION LOSS - SHUNT PORT

FINLINE COUPLER #2

8/6/75 F.F.

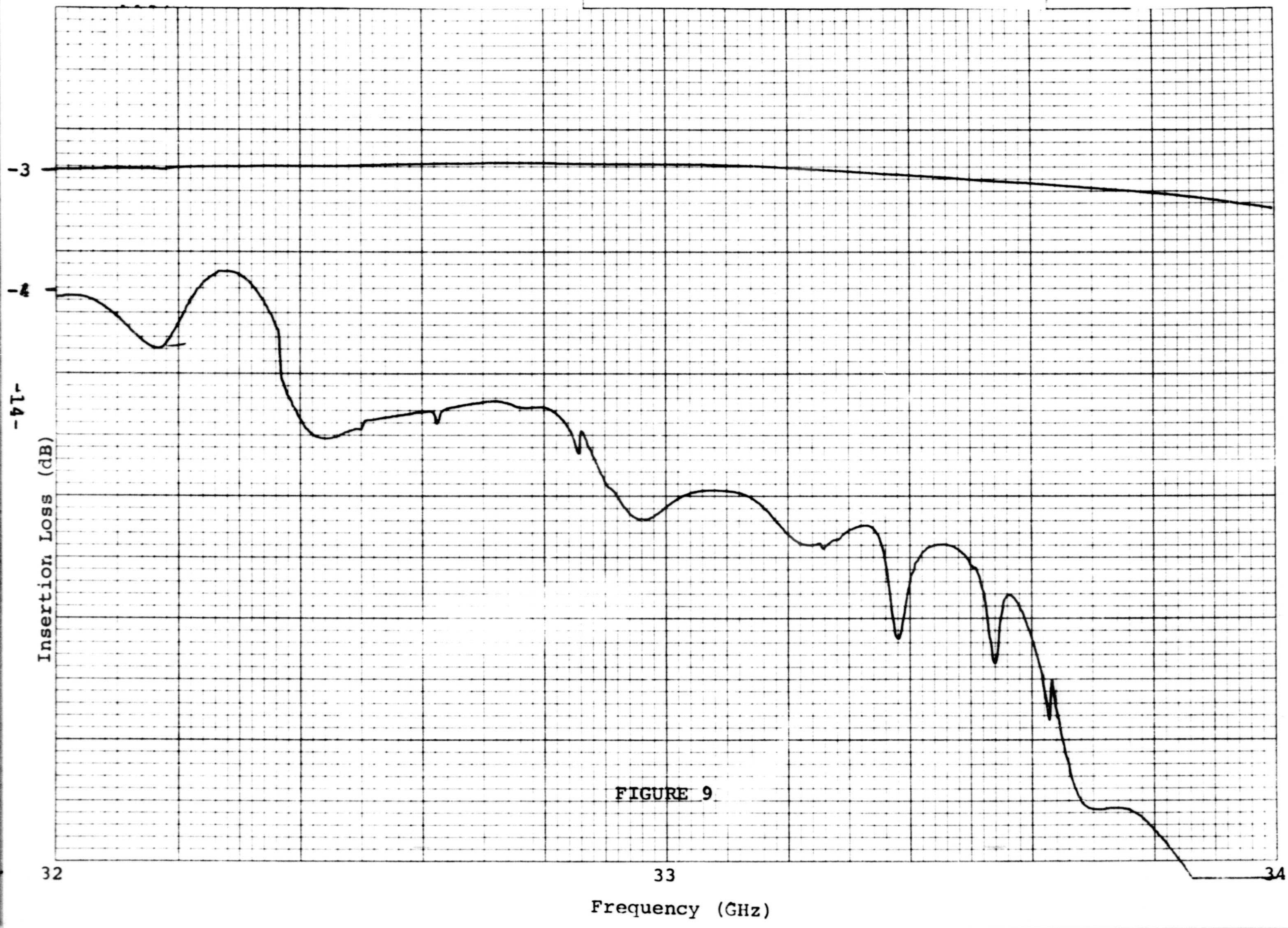


FIGURE 9

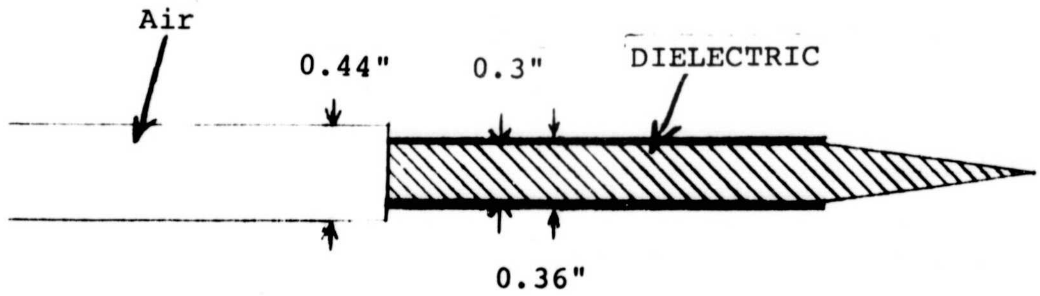


FIGURE 10. CIRCULAR WAVEGUIDE LAUNCHER

The conical horn taper as shown in Figure 2 of the appendix was designed to have the same flare angle as the corrugated horn (26.1°). The horn tapers down to the 1 inch diameter of the 6.6 GHz coaxial launching section.

## VII. ANTENNA PATTERNS

Figures 11 and 12 represent the E- and H-plane radiation patterns at 6.6 GHz. These figures show the co-polarized and cross-polarized envelope for ±60°. As can be seen in the patterns the polarization isolation far exceeds the original specification of 25 dB isolation between the two linear polarizations. A summary of the important parameters such as frequency versus cross-polarization, 3 dB beamwidth, 10 dB beamwidth and the 60° beamwidth is tabulated in Table II.

TABLE II. FEED PERFORMANCE

| Figure | Freq. | X-Pol Isolation | 3 dB B.W. | | 10 dB B.W. | | @ 60° B.W. | |
|---|---|---|---|---|---|---|---|---|
| | | | E | H | E | H | E | H |
| 11 | 6.6 | >35 dB | 18° | - | 42° | - | -18.6 dB | - |
| 12 | 6.6 | >30 dB | - | 14° | - | 25° | - | >-30 dB |
| 13 | 10.7 | >35 dB | - | 19.5° | - | 25° | - | -22 dB |
| 14 | 10.7 | >35 dB | 18° | - | 41° | - | -22 dB | - |
| 15 | 18.5 | - | 52° | | 80° | | -4.5 dB | |
| 16 | 21.5 | - | 45° | | 68° | | -6.8 dB | |
| 17 | 33.0 | - | 30° | 33° | 89° | 82° | -8.5 dB | -7.3 dB |

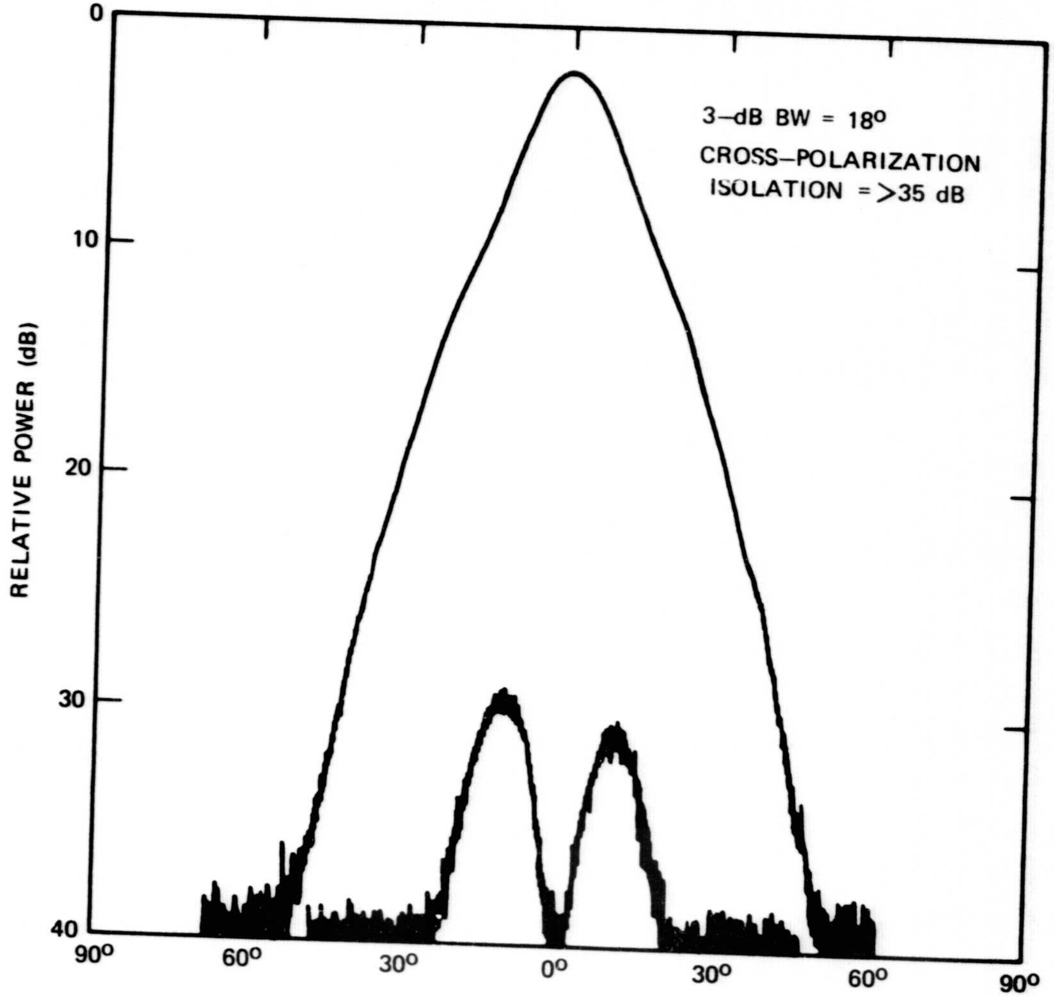


FIGURE 11. 6.6 GHz E-PLANE PATTERN

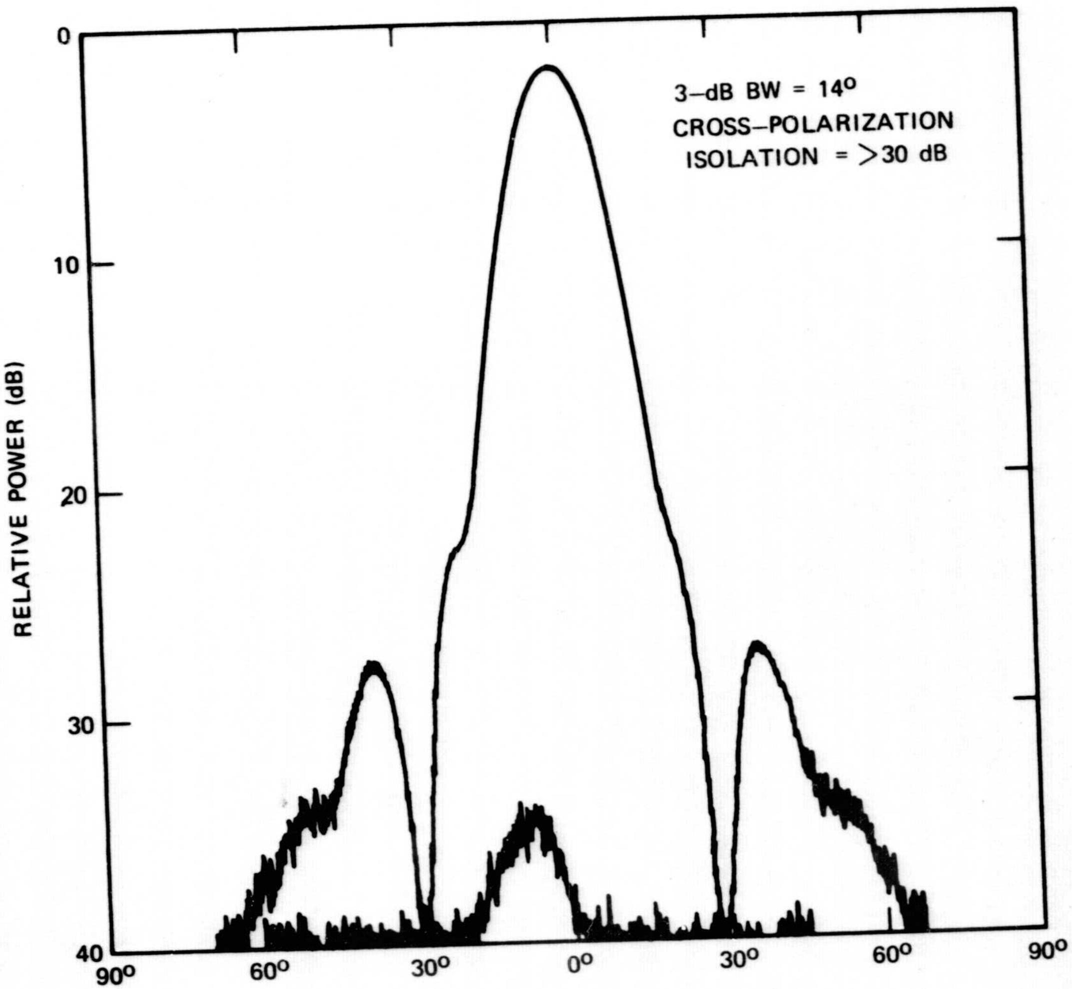


FIGURE 12. 6.6 GHz H-PLANE PATTERN

The 18.5, 21.5 and 33 GHz corrugated horn used in the original contracts was replaced by a conventional conical horn with a flare angle of 26.1°. The corrugations created a surface wave effect at 10.7 GHz due to the fact the corrugations were less than a quarter wavelength deep at 10.7 GHz. Figures 13 and 14 represent a vast improvement over the original 10.7 GHz radiation patterns. This improvement is due to the removal of the 18.5, 21.5 and 33 GHz corrugated horn. The cross-polarization isolation exceeds the original specification of 25 dB.

The three higher frequencies were taken using a conventional dielectric rod launching antenna. The diameter is 0.44" while the length of the taper was varied. See Figure 9 in the appendix for the exact dimensions of each of the four rods.

Figures 15 and 16 compare the on-axis gain of the four rods versus an open ended waveguide at 18.5 and 21.5 GHz. Sidelobe levels versus rod taper is also available from the patterns. Figure 17 represents the 33 GHz E- and H-plane patterns. The on-axis gain at 33 GHz is +6.4 dB with respect to an open ended circular waveguide.

## VIII. CONCLUSIONS

This study has shown the feasibility of employing five narrowband frequencies 6.6, 10.7, 18.5, 21.5 and 33 GHz within a single antenna feed. Basically, the feed consisted of a coaxial section to launch the two lower frequencies with the center conductor being used as a circular waveguide for the higher frequencies. The $TE_{11}$ mode was employed in both geometries enabling orthogonal polarizations at each frequency to be achieved. Orthogonal coaxial probes were used at the lower frequencies while a finline coupler was used for the higher frequencies.

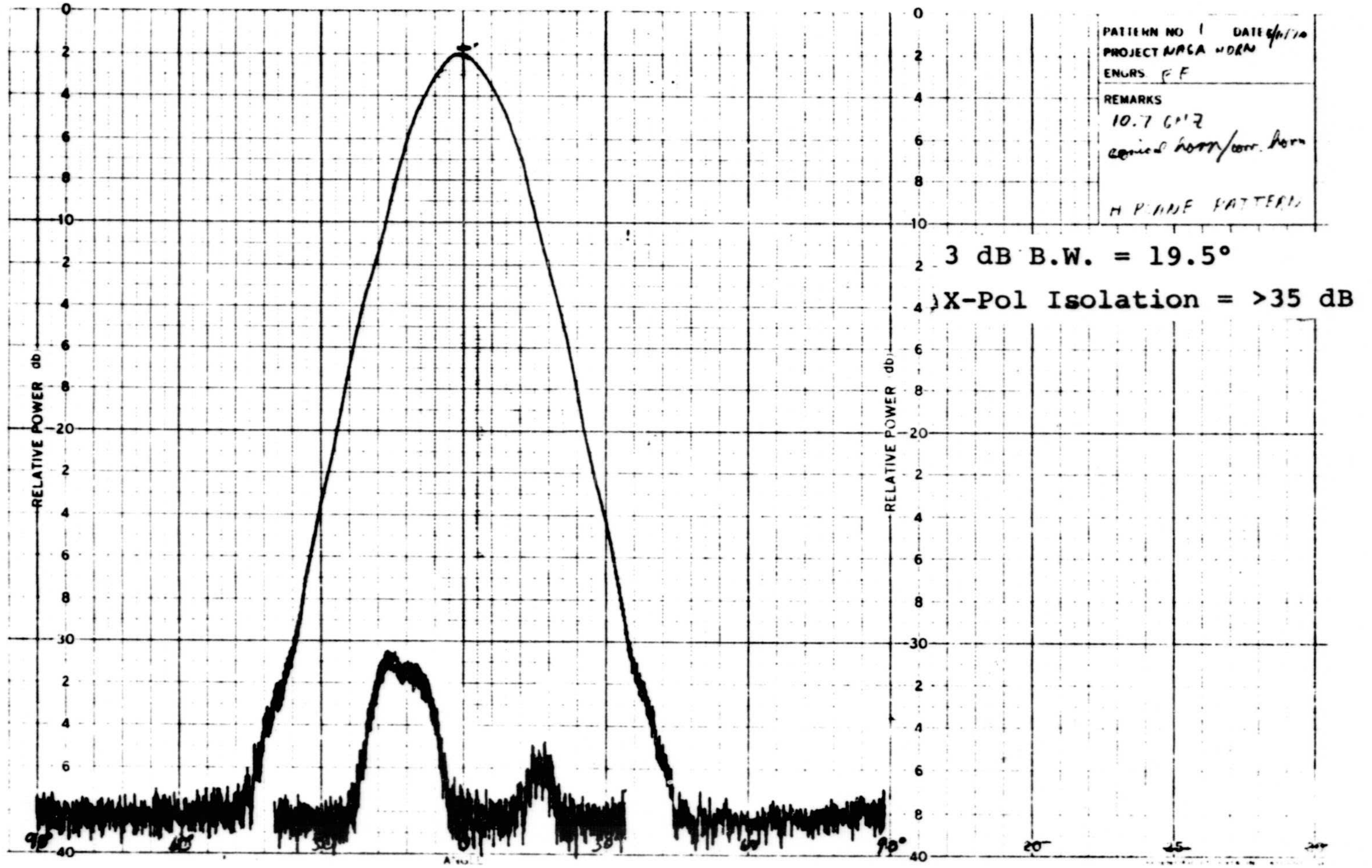


FIGURE 13. 10.7 GHz H-PLANE PATTERN

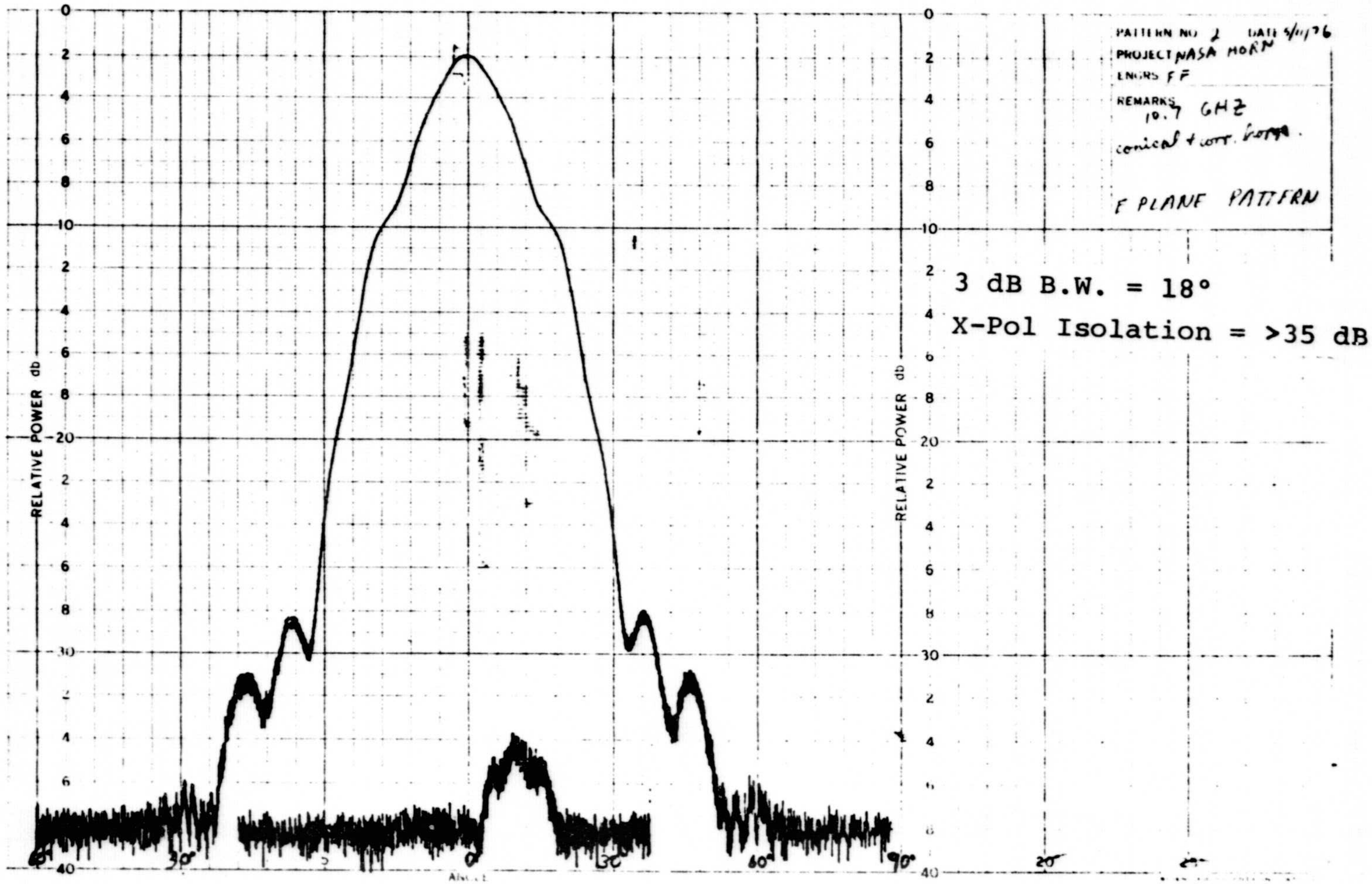


FIGURE 14. 10.7 GHz E-PLANE PATTERN

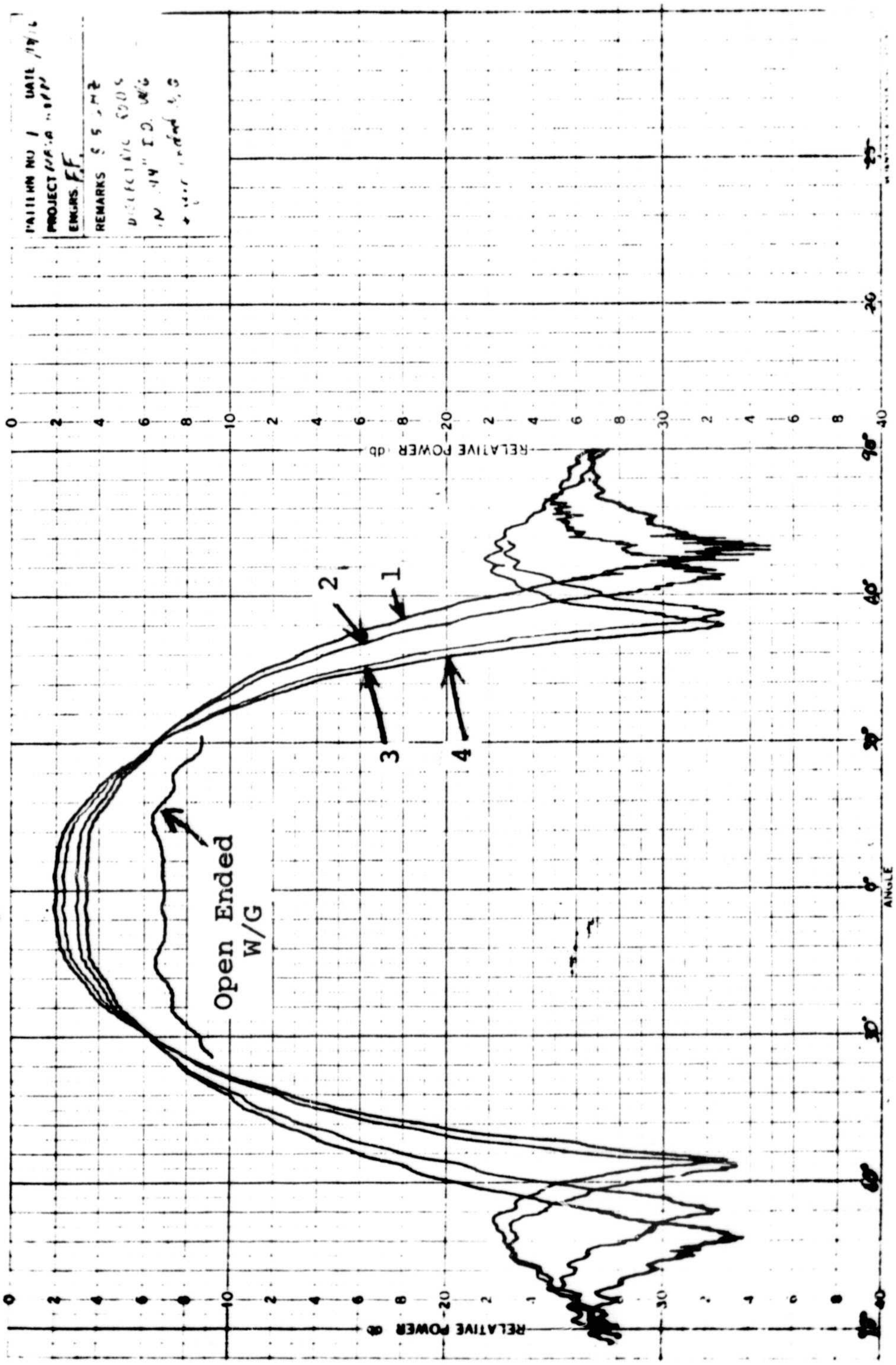


FIGURE 15. 18.5 GHz PATTERNS

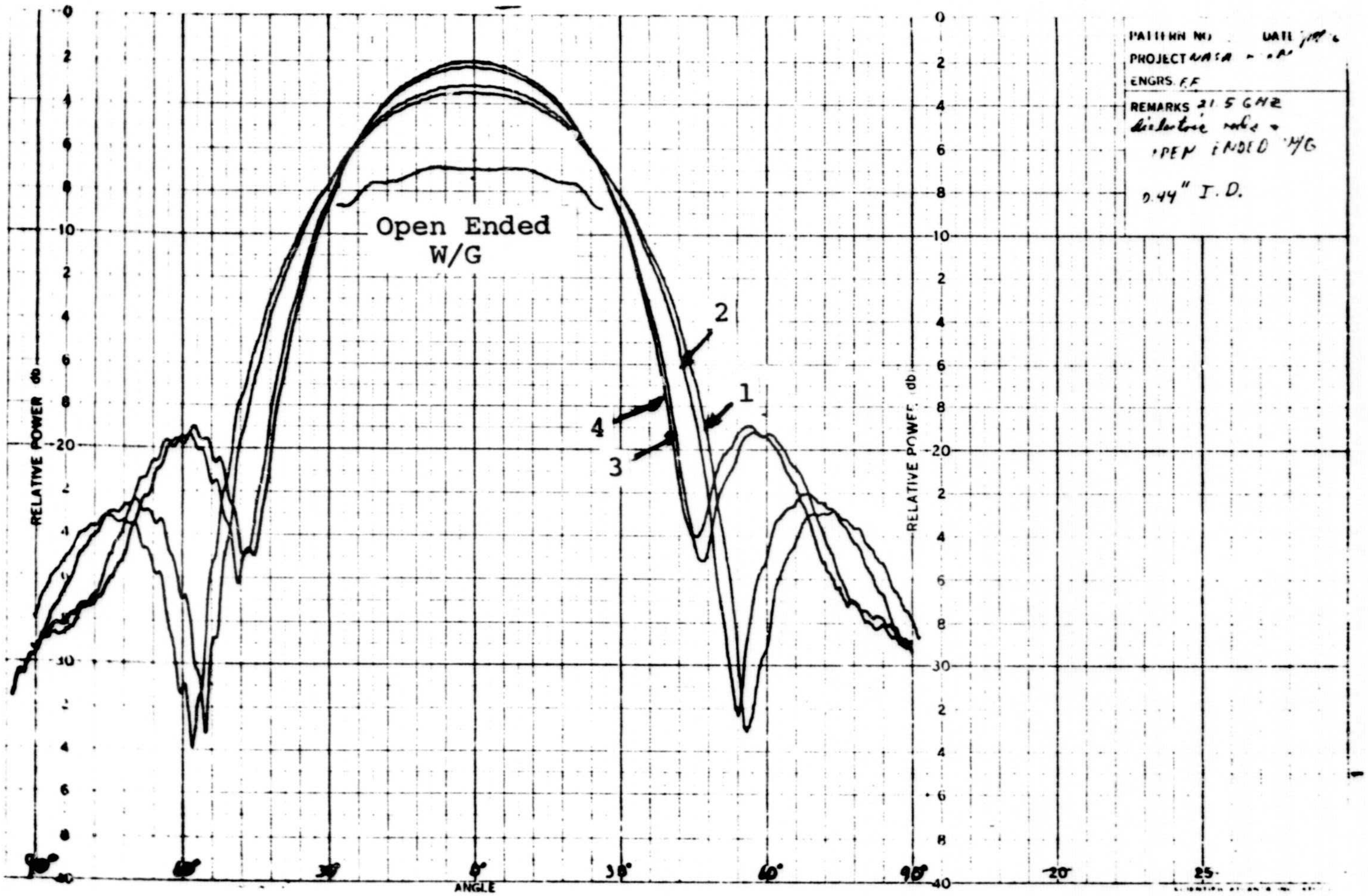


FIGURE 16. 21.5 GHz PATTERNS

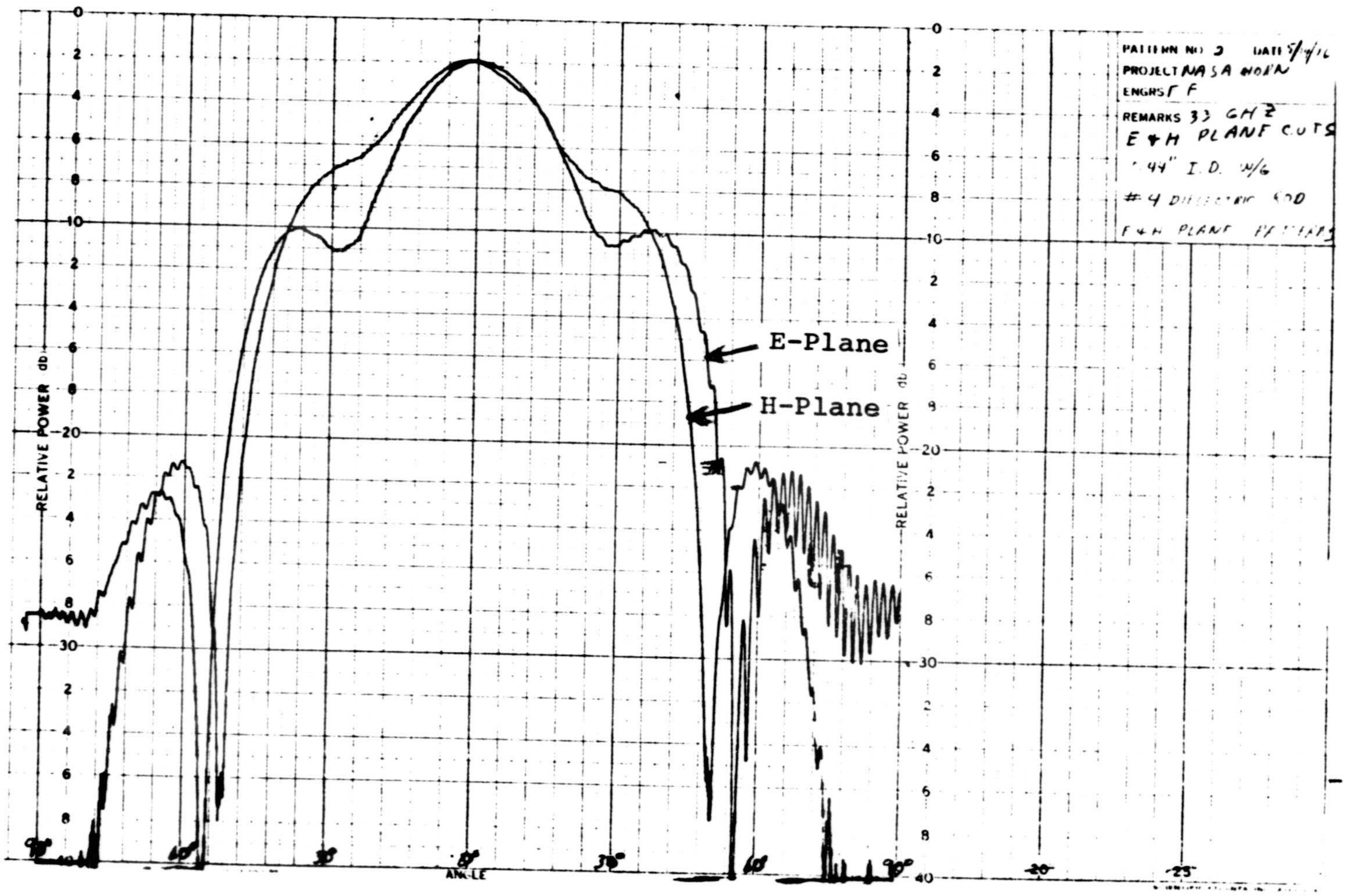


FIGURE 17. 33 GHz E- AND H-PLANE PATTERNS

Isolations greater than 30 dB between the ten ports have been achieved with good input return losses (>15-20 dB).

The possibility of achieving wideband feed performance exists with the present design. E- and H-plane radiation patterns have been recorded for all ten ports showing that mode control has been adequately achieved.

It is possible to minimize the difference in the location of the 5 phase centers. The dielectric rod launcher can be slid in or out to coincide with the 6.6 and 10.7 GHz phase center.

## REFERENCES


(1) Final Report, "Fabrication and Test of a Five Frequency Wideband Feed," NASA (GSFC) Contract NAS5-20637, December 1974.

(2) S. D. Robertson, "The Ultra-Bandwidth Finline Coupler," Proceedings of the IRE, June 1955.

(3) Final Report, "A Multifrequency Coaxial Feed Horn Antenna: A Design Study," NASA (GSFC) Contract No. NAS5-21986, February 1974.

## APPENDIX: DESIGN DRAWINGS

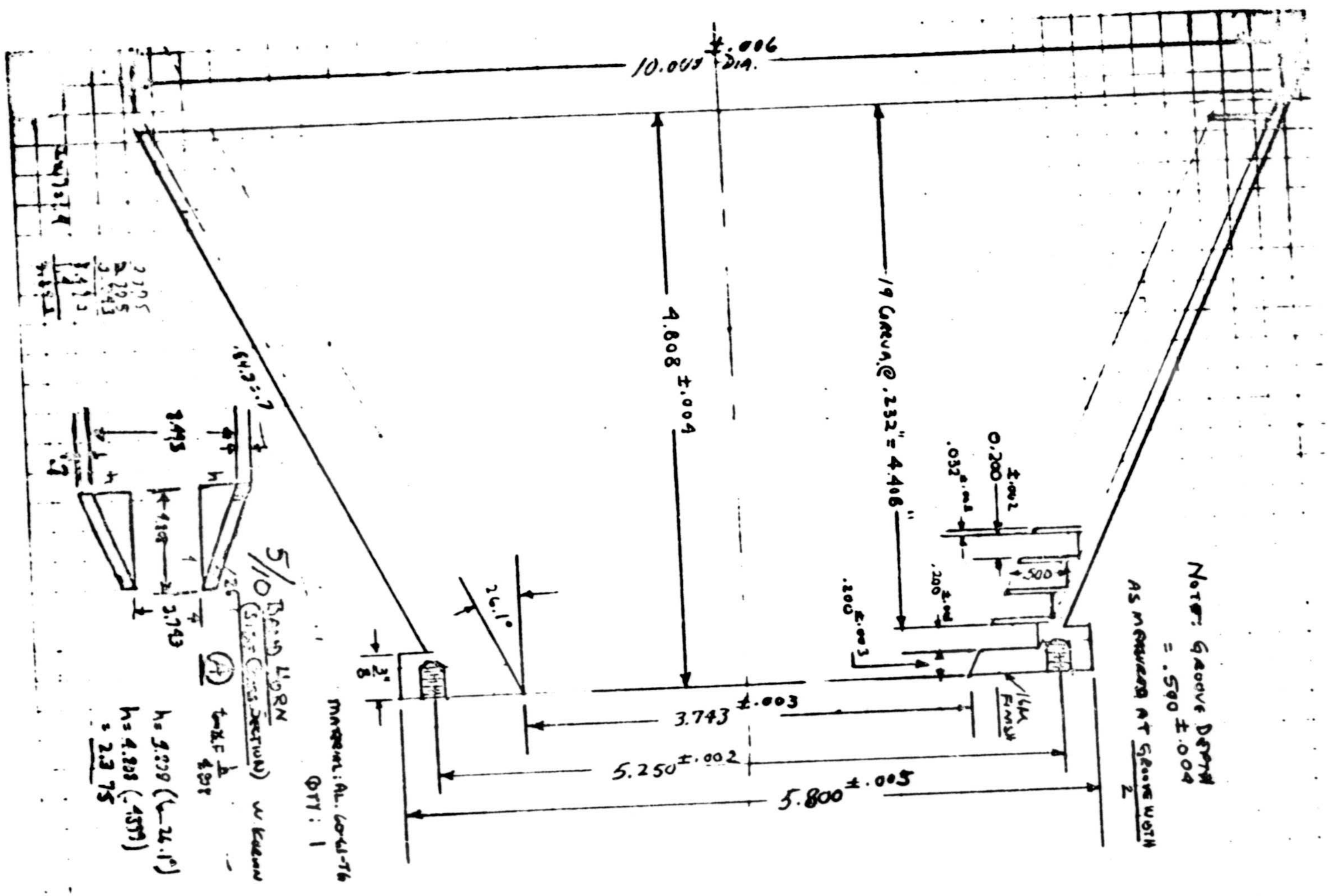


FIGURE 1A. 6.6 AND 10.7 GHz CORRUGATED HORN

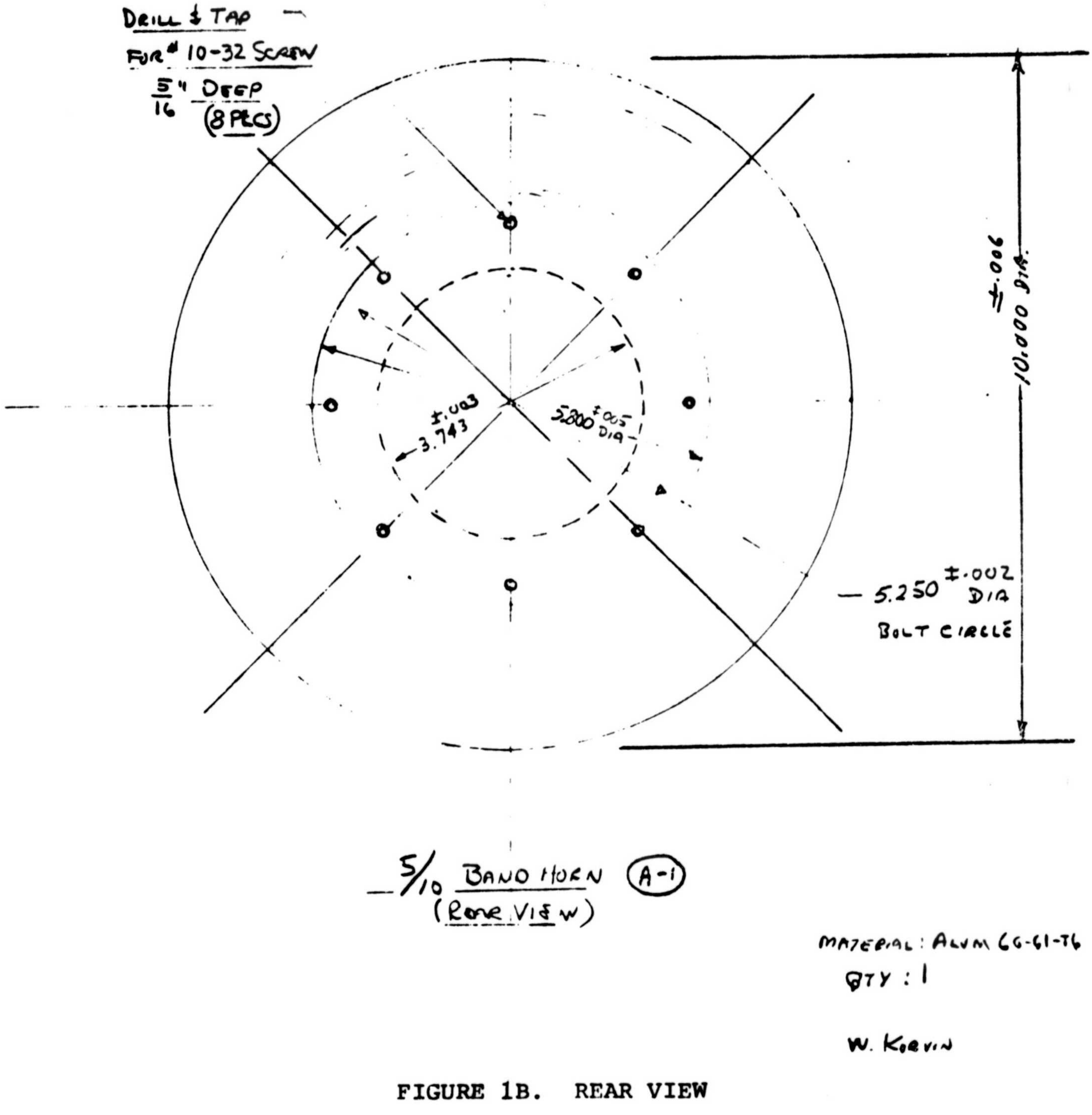


FIGURE 1B. REAR VIEW

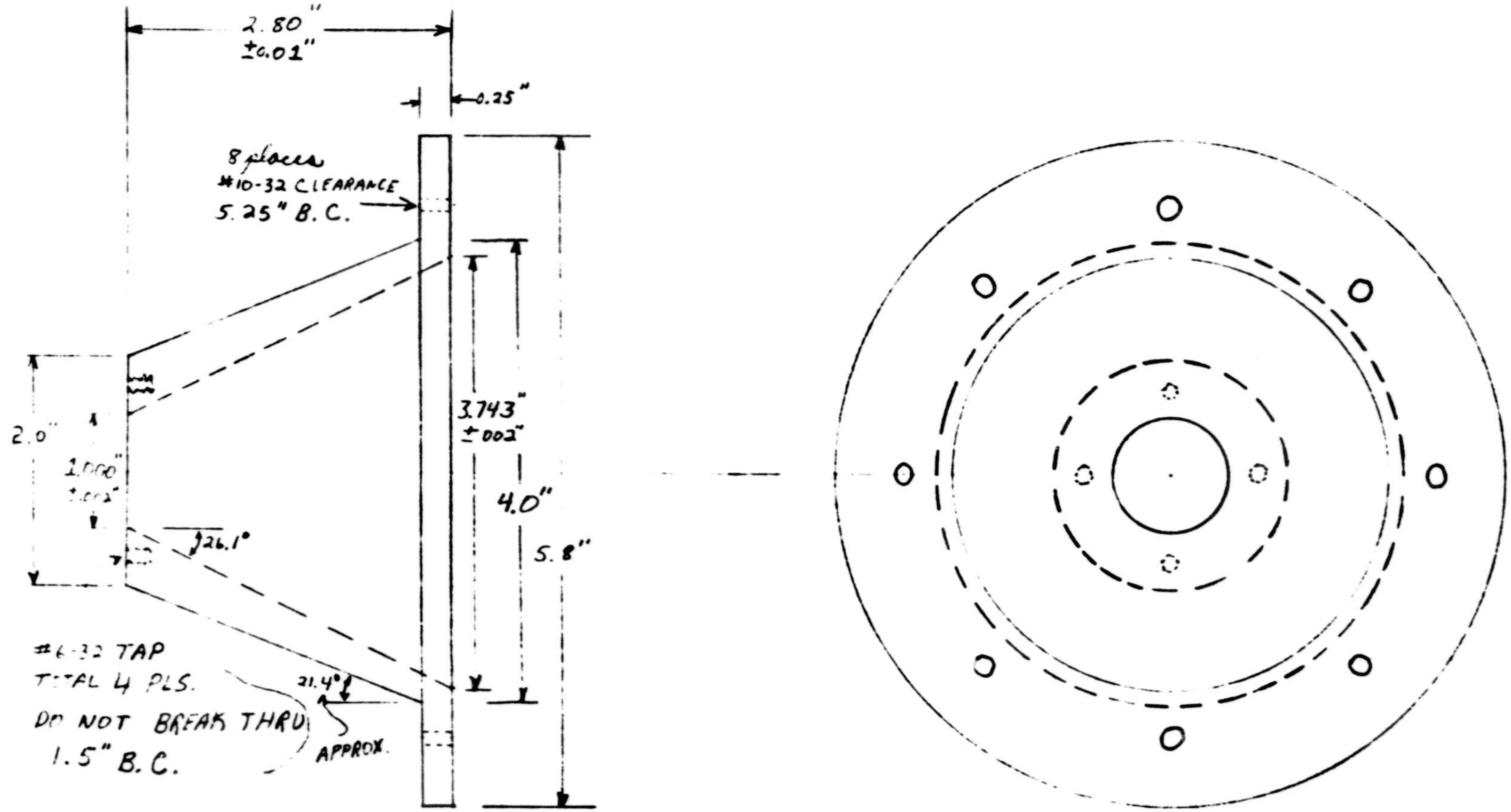


FIGURE 2. CONICAL HORN TAPER

| ISSUE | ENGR FF / DRAWN 4/30/76 | TITLE CONICAL HORN | COMMUNICATIONS SATELLITE CORP / NASA / NO OF SHEETS PER SET | SHEET 1/1 |
|---|---|---|---|---|

CSC 573

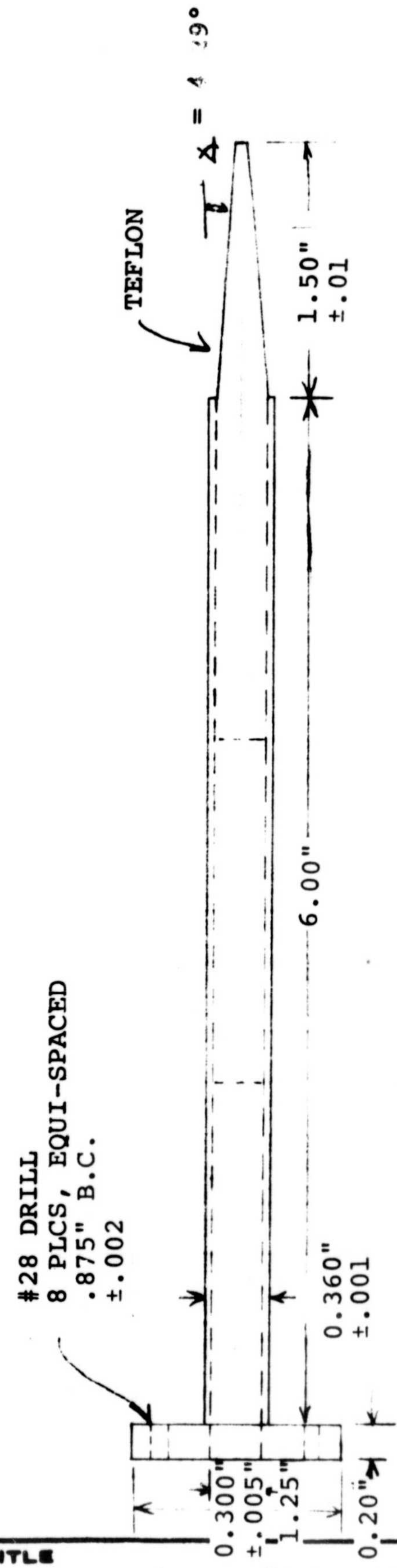


FIGURE 3. DIELECTRIC ROD ANTENNA

MS-2894
W/O 13316
151-6056

| ISSUE | ENGR. FF | TITLE DIELECTRIC ROD LAUNCHER | COMMUNICATIONS SATELLITE CORP. |
|---|---|---|---|
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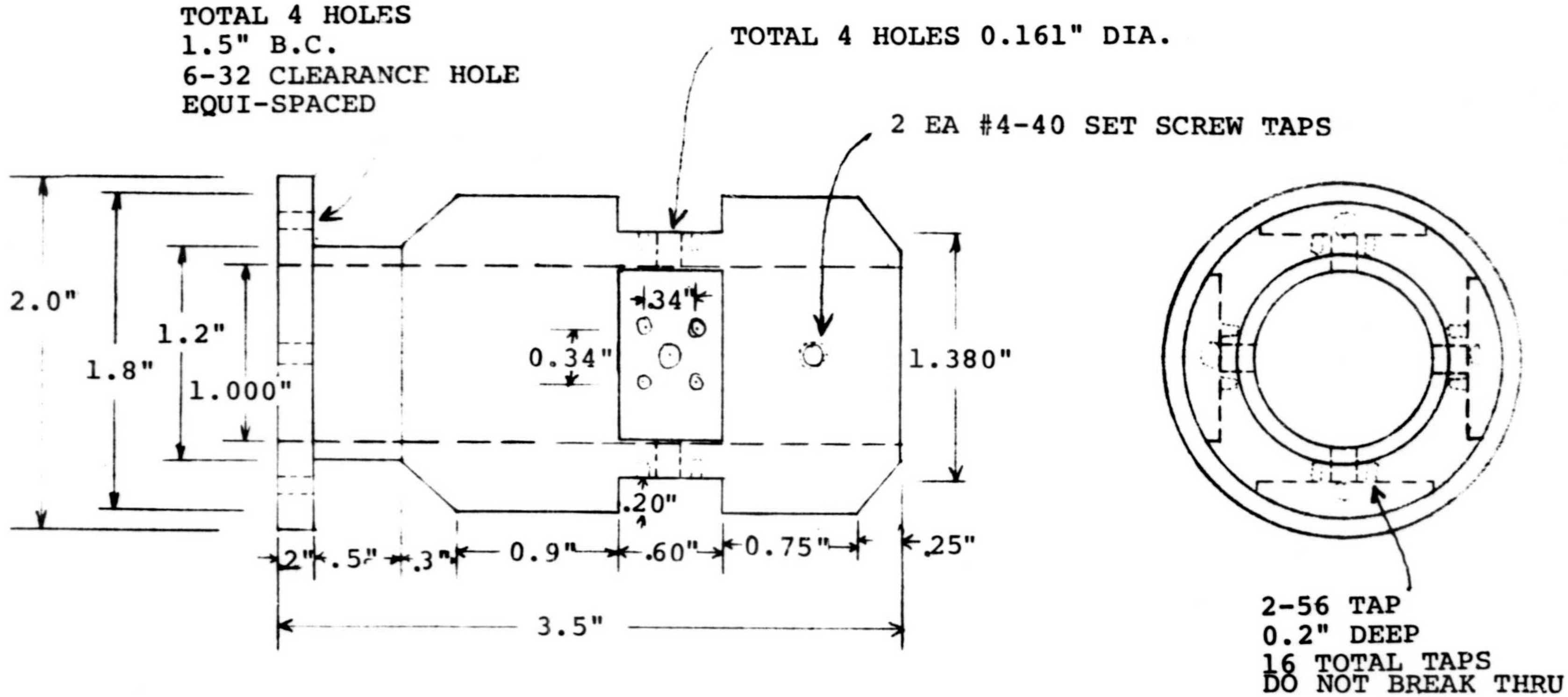


TOLERANCES:
.X = ±.1"
.XX = ±.05"
.XXX = ±.001"

FIGURE 4. 6.6 GHz LAUNCHING SECTION

| ISSUE | ENGR. ELF<br>DRAWN 6/1/76 | TITLE 6.6 GHZ LAUNCHER | COMMUNICATIONS SATELLITE CORP.<br>NASA HORN<br>NO. OF SHEETS PER SET | SHEET 1/2 |
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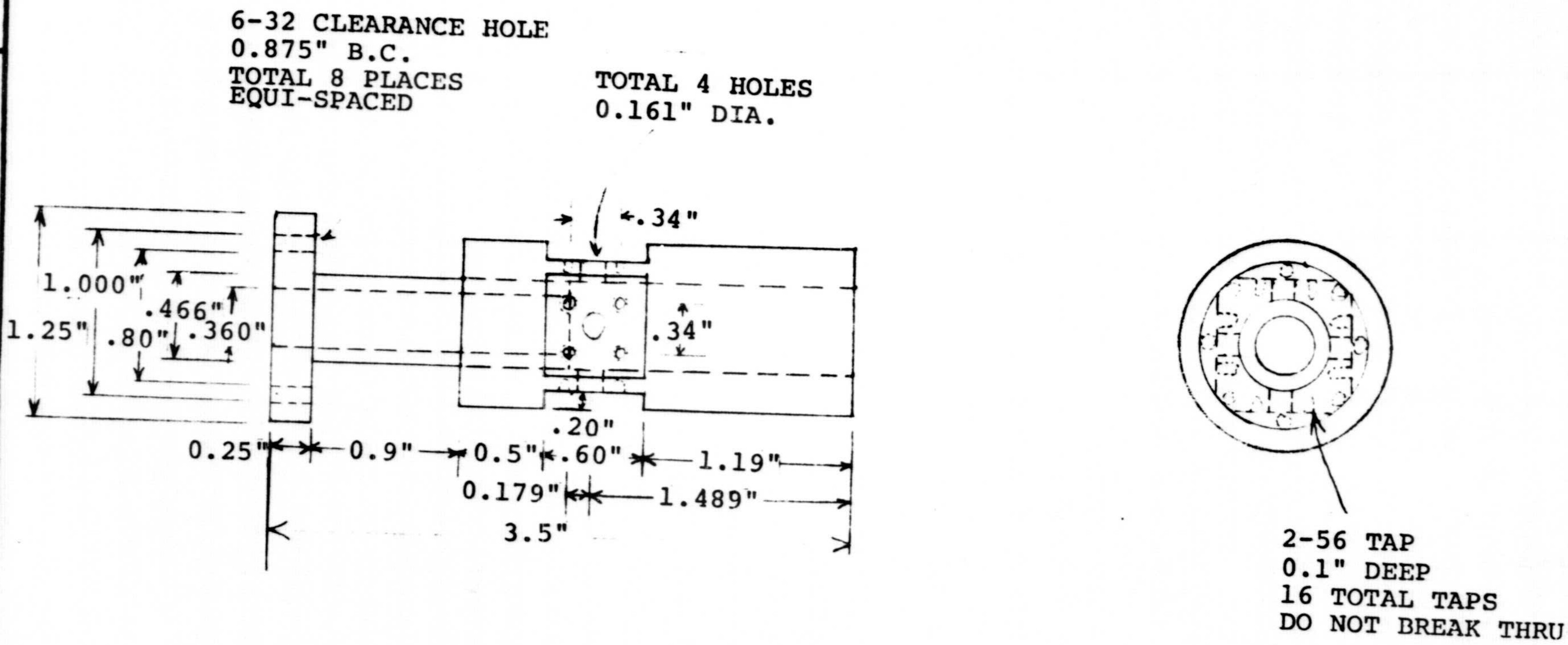


TOLERANCES:

.X = ±.1"
.XX = ±.05"
.XXX = ±.001"

FIGURE 5. 10.7 GHz LAUNCHING SECTION

| ISSUE | ENGR. | TITLE | COMMUNICATIONS SATELLITE CORP. | |
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| | DRAWN 6/1/76 | | NO. OF SHEETS PER SET | 2/2 |

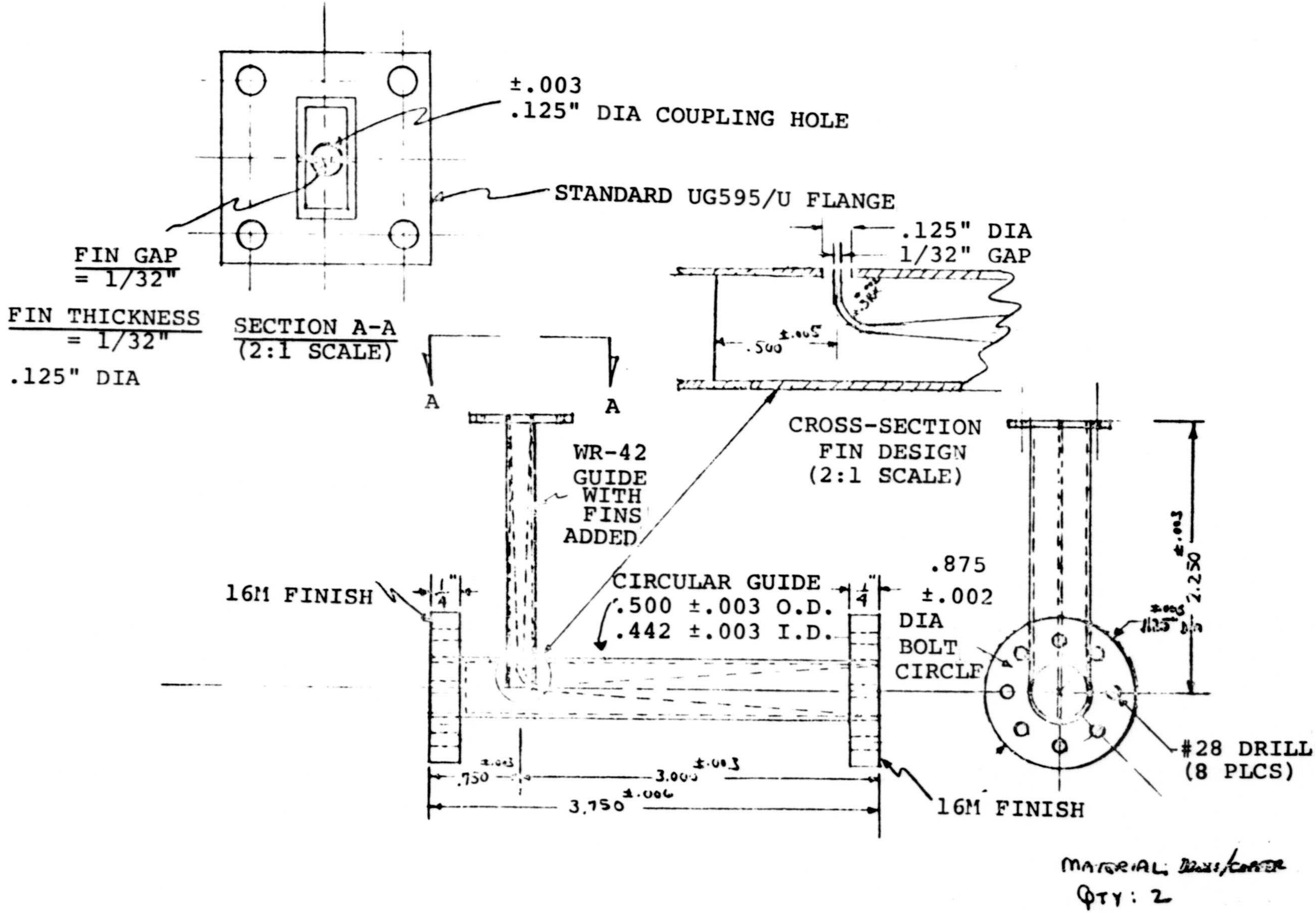
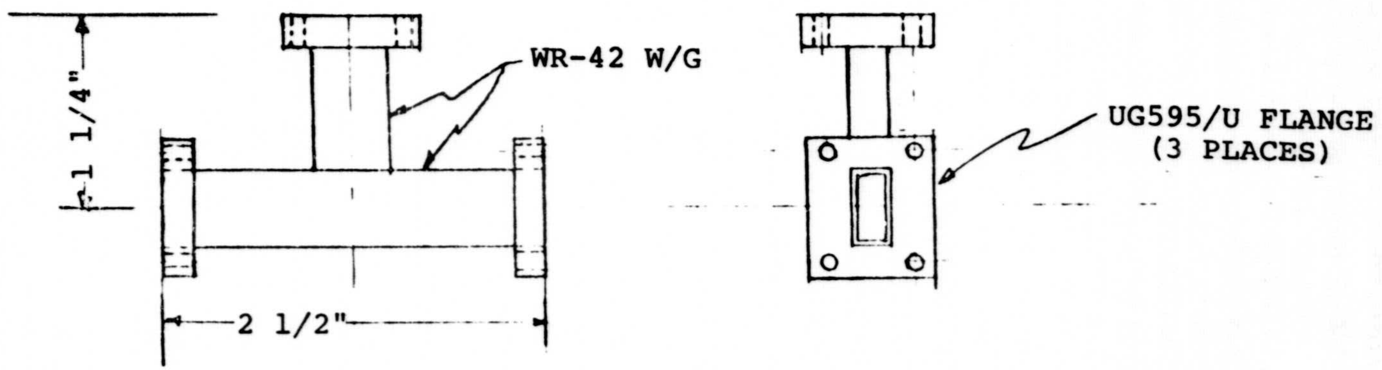



FIGURE 6. FINLINE COUPLER




MATERIAL: BRASS
QTY: 2
(PROVIDED BY ENGR)

FIGURE 7. WR-42 SHUNT TEE

BILL KORVIN, JAN 74

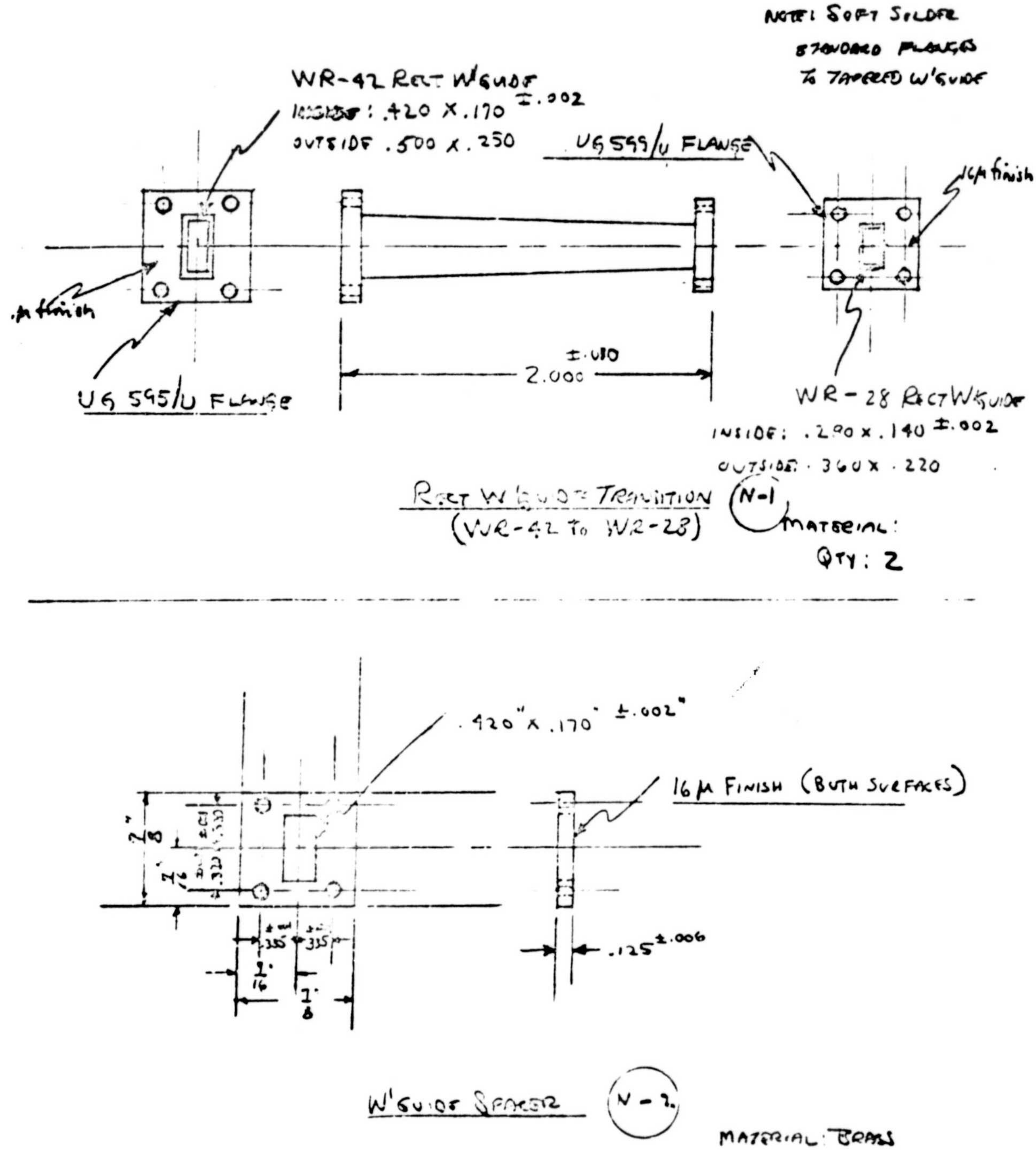
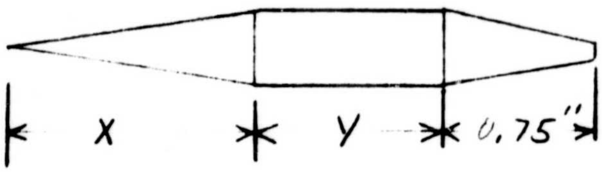



FIGURE 8. WR-42 TO WR-28 W/G TAPER




DIA = 0.44"

| ROD # | X | Y |
|---|---|---|
| 4 | 1.5" | 0.75" |
| 3 | 1.387" | 0.5" |
| 2 | 1.125" | 0.375" |
| 1 | 1.0" | 0.375" |

FIGURE 9. DIELECTRIC ROD DIMENSIONS

| ISSUE | ENGR. FF / DRAWN | TITLE | COMMUNICATIONS SATELLITE CORP. |
|---|---|---|---|
| | | TEFLON DIELECTRIC ROD | NASA HORN; NO. OF SHEETS PER SET; SHEET 1/1 |